An Assessment of the NTHMP Inundation Mapping Activity
("Lessons learned and how to go forward ...")

A Report to the NTHMP Steering Group

Prepared for the
14-15 November 2000 Meeting
Hilo, Hawaii
by

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TIME Co-Directors

1. Background

During the May 10-11, 2000 meeting in Seattle, Washington, the Steering Group requested the following action of TIME:

ACTION ITEM: The Steering group requested an assessment of lessons learned and how to go forward on where and how to map areas.

ACTION: TIME to collect and summarize data.

This report responds to that request. A general call for input to this action item was issued to the community via e-mail. The responses received are included in Appendix A.

2. Abbreviated History

The NTHMP has been engaged in the production of inundation maps for selected communities since 1997 up to the present time, a total of 4 years. A decision was made early on to abandon the original plan to use 1-D inundation models, based on the belief that this technology was inadequate in all but the very simplest of physical settings. Instead, full 2-D modeling was adopted as the preferred, highest quality technology available, even though it was understood that this approach would likely be more expensive and time-consuming.

It was decided that each State would receive NTHMP funds on a rotating basis, to hire and pay contractors for specific inundation mapping projects. In addition, it was decided to establish a Center for Tsunami Inundation Mapping Efforts (TIME) to to "assist Pacific states in the development, maintenance, and upgrade of inundation maps; to archive bathymetry and topographic data; and to develop computational bathymetry and topographic models." The TIME Center was initially established in Newport, OR. In January 2000, it was moved to PMEL at Seattle, Washington and Vasily Titov joined Frank González as a co-director.

2.1 Funding

Funding each of the four fiscal years has consisted of $400K total, before taxes, with $200K provided for State contracting and $200K for the operation of the TIME Center. In FY1997, Washington and Oregon were the first recipients of NTHMP map funding and the first mapping contract was awarded to the Oregon Graduate Institute to map communities in both Oregon and Washington. The TIME Center was also established in Newport, Oregon, with Frank González as Acting Director. In FY1998, Alaska and California received funding, and contracts were awarded to the University of Alaska and University of Southern California to perform inundation mapping in their respective States. In FY1999, NTHMP funding was distributed among Hawaii, Oregon and Washington, with contracts awarded to OGI and the University of Hawaii and in FY2000, Alaska, California and Hawaii received equal funding for inundation mapping contracts. Table 1 summarizes this funding history.

Table 1. Inundation mapping funding history, in thousands of dollars after taxes.

	FY97	FY98	FY99	FY00	Totals
ALASKA		97.6		58.8	156.4
CALIFORNIA		97.6		58.8	156.4
HAWAII			97.6	58.8	156.4
OR& WA	195.2		97.6		292.8
TIME	195.2	195.2	195.2	176.3	761.9
Totals	390.4	390.4	390.4	352.7	1523.9

Over the four year period, $762K was distributed to TIME and $762K was distributed to the five states. Funding was distributed approximately evenly to individual states, but Washington and Oregon each received about $10K less over the four year period.

It is also important to note that these figures do not include the state Mitigation Program funding, nor the considerable resources contributed in-kind by state agencies.

2.2 Map Production

Typically, the production of inundation maps involves a number of stages:

(0) Model development and testing. May not be necessary if the contractor has been actively exercising a tsunami inundation model as part of a research or applied engineering project, for example.

(1) Identification of priority communities. The state identifies communities based on population, previous tsunami history, etc., including preliminary estimates from TIME on the availability of bathymetric and topographic data for the areas of interest.

(2) Specification of computational grid coverage. The modeler communicates the coordinates of the desired grid to TIME.

(3) Grid development. First, TIME searches for and acquires the best available bathymetric and topographic data to produce the multiple imbedded finite difference grids (or the single finite element grid) that comprise the required computational grid for each specific community. As a practical matter, this has also meant that a significant digitizing effort must be undertaken to fill in data holes. Second, these data are either forwarded to the modeler, who then constructs the grids (as has been the case for OGI modeling for Washington and Oregon) or TIME performs the actual merging of the bathy/topo data to form the required finite difference grids (as has been the case for modeling in Alaska and California). It should be noted that Hawaii has been developing its computational grids independently, so far.

(4) Source development. The state and the modeler, with some participation by TIME, decide on the specification of tsunami sources that represent "credible worst case scenarios" in terms of the initial conditions for the numerical model simulations.

(5) Model simulations. The model is run with appropriate source conditions. Products are derived from the results to aid visualization and analysis -- animations, time series, derivative quantities such as arrival times, etc.

(6) Quality control. This is a collaborative effort by state officials, the modeler, and TIME. The model results are examined for reasonableness, and compared with any historic observations or pre-historic information that might be available.

(7) Final interpretation and analysis. The final inundation map is the product of numerical modeling modified by professional judgement that reflects specific local knowledge and common sense judgements regarding inconsistencies or questionable features.

Typically, a number of these stages can and do run concurrently, with iterative exchanges common between state officials, the modeler and TIME. In particular, grid development and source development (stages 3 and 4) are usually conducted in parallel, and an iterative process involving model simulations and quality control (stages 5 and 6) is the norm.

Table 2 summarizes the current productivity of the NTHMP mapping program, in terms of the number of "maps" and "communities" covered. A "map" refers to the region covered by a particular computational grid, which may include more than one "community." A rough estimate of the number of communities covered by each map was obtained by counting the number of coastal towns indicated on a Road Atlas corresponding to the area.

Table 2. NTHMP inundation map production, FY1997-2000.

	CALIFORNIA	**OREGON**	**WASHINGTON**
Maps & (Communities)	San Diego (11) Los Angeles/Long Beach (10) Santa Barbara (9)	Seaside Astoria Warrenton Gold Beach	Gray’s Harbor County (17) Pacific County (11)

	San Francisco/San Mateo (6)	Coos Bay	
Totals	4 (36)	5 (5)	2 (28)

In each state, map production has taken longer to achieve than anticipated. The time it takes to produce each map depends on a number of factors, including

(a) possible delays in the transfer of funds to the modeler,
(b) whether or not the modeling capability is fully in place when the funds are received,
(c) the difficulty of computational grid development,
(d) the difficulty of defining an appropriate source
(e) the intrinsic difficulty or ease in modeling a particular geographic region.

Table 3 attempts to summarize a few of these factors for each state.

Table 3. Factors affecting map production in each state.

	Funding Transfer Date	**Initial Modeling Capabilities in Place**	**Difficulty of Grid Development**	**Substantial Completion Date**
OR & WA	May, 1997	ADCIRC model running at OGI	Digitized by TIME: Topography Shoreline barriers	April, 1999
CA	Feb-Aug 1998	MOST model running at USC	Digitized by TIME: Topography NOS Smooth Sheets	May, 2000
AK	May, 1998 ?	Model under development	Large Data Holes Digitized by TIME: Topography NOS Smooth Sheets	
HI	Fall, 1999	Models under development	Under development by Hawaii	

Items (c) and (d) have caused significant delays in map production. Item (c) involves difficulties in acquiring bathymetric and topographic data, the quality of the bathy/topo data and the associated ease or difficulty in producing the merged bathy/topo computational grid. Item (d), source specification, is not listed in Table 3, but this can also be an important factor that delays production of an inundation map. Forecasting the location of a future earthquake and/or a landslide is problematic, especially if the goal is to provide an appropriate degree of detail on the magnitude and spatial distribution of the tsunami-producing energy that will be released. A substantial amount of time was spent in Oregon, Washington and California on this issue, and Alaska and Hawaii are now engaged in a similar effort.

3. Lessons Learned

3.1 Map Utility. The judgement of most tsunami community scientists is that, although not perfect, inundation models are accurate enough to provide useful emergency management guidance. This judgement is based on years of model testing and comparison with analytic models, laboratory data, and field observations. But the usefulness of inundation maps also requires the acceptance and utilization of that map by a community.

Now, after four years of map production, we find that community response to the NTHMP mapping effort has been overwhelmingly favorable. Many communities are vigorously lobbying for a map and there is now considerable, unmistakable pressure on the NTHMP to speed up map production. Furthermore, communities are aggressively exploiting these maps for emergency management purposes. Evacuation maps are being produced that include other valuable information besides recommended escape routes -- gathering places, hospitals and other important infrastructure components.

We conclude that

I. NTHMP inundation maps have been accepted by communities and are proving to be useful emergency management tools.

3.2 Map Cost and Production Time. Based on Tables 1, 2 and 3 we can derive estimates on current map production time and cost. Although Alaska and Hawaii have not yet completed maps, Table 4 provides an estimates based the total provided to all states so far, as well as the funding provided only to those states that have produced maps, i.e. California, Oregon and Washington and, finally, to each of these three states separately. Again, it is important to note that these estimates do not include the state Mitigation Program funding, nor the considerable in-kind resources contributed by state agencies.

Table 4. Map production unit cost estimates, including TIME operating costs, excluding state in-kind support.

	All States	**CA, OR & WA**	**CA**	**OR**	**WA**
Funding	$ 1,524 K	$ 1,211 K	$ 342.2 K	$ 341.6 K	$ 341.6 K
Number of Maps	11	11	4	5	2
Communities	69	69	36	5	28
Cost/Map	$ 140 K	$ 110 K	$ 85.6 K	$ 68.3 K	$ 170.8 K
Cost/Community	$ 22 K	$ 18 K	$ 9.5 K	$ 68.3 K	$ 12.2 K
Years to Completion			2	2 (combined)	
Maps/Year			2	3.5 (combined)	

A more meaningful unit cost analysis would utilize estimates of the coastal population at risk; these estimates are not currently available. A "cost/km of coastline" estimate would be difficult to interpret since the modeling strategy was somewhat different in each state; for example, the Washington/Oregon effort utilized much larger computational grids than those used in California. Similarly, the "cost/community" figures listed in Table 4 are difficult to interpret, since each state has a different coastal population distribution and a different mapping strategy. Washington chose to publish inundation maps over the entire extent of the large computational grids used in that state, but Oregon chose to publish inundation maps for single communities at a time.

Early in the NTHMP program, informal estimates were made that a typical mapping effort could be completed for about $50K. This estimate now appears to be low, as the "cost/map" figures in Table 3 suggest. The cost of mounting and completing a single effort to produce an inundation map for a given coastal area is on the order of $100K. This estimate includes TIME support, but excludes state in-kind support. The relatively high apparent cost for Washington is somewhat misleading, and reflects the fact that the two maps produced for that state covered much larger areas than the individual inundation maps produced by Oregon and California. This suggests that

II. The current cost of producing a typical inundation map is on the order of $100K, excluding state in-kind support. However, the map may cover more than one community, depending on the coastal population density of the area.

Table 3 also indicates that production time, i.e., the time to substantially complete the mapping effort in California and in Washington/Oregon was similar -- about 2 years -- while Alaska has not completed a map in the two years since funding started for this effort. Alaska poses a more difficult grid development task (discussed below) and has also been more involved in model development than California or Washington/Oregon. Both of these factors have slowed map production in Alaska, and the total time to develop this first map will likely be 2.5-3 years.

3.3 Technical Problems affecting map production

More research is needed to improve both model physics and computational algorithms. However, current modeling capabilities are indeed adequate to provide useful emergency management guidance and, as was pointed out by several community members (see Appendix A), as a practical matter

III. Map production is delayed primarily by grid development problems and source specification uncertainties.

3.3.1 Grid development. The task of producing merged bathy/topo grids has been more difficult than expected, and there have been delays in the completion of these grids for California, Washington/Oregon, and Alaska. Time-consuming digitizing efforts have been required to fill in gaps in the available bathymetric and/or topographic data, and the methodology for merging bathymetric and topographic data into a single grid is not yet mature. Specific technical problems that complicate the grid development task are:

a. Inadequate coverage. In a given region, a lack of coverage can be due to:

(i) No surveys in the region. Alaska is particularly deficient in survey coverage.

(ii) Old surveys, but no digital data. In this case, old NOS "smooth sheets" may be digitized. The estimated cost is approximately $2-4K per typical sheet, and up to 10 sheets may be needed for a particular regions, so that a total cost of $20-40K could easily be added to grid development.

(iii) Intertidal data gap. NOAA nearshore bathymetric data are not generally collected above the MLLW line, because the traditional NOS mission emphasizes safe navigation. But USGS topographic data are not generally available below the legal definition of the shoreline, i.e. the MHW level. Thus, the intertidal data gap exists because neither agency has assumed responsibility for the region between MLLW and MHW. Alaska tends to be most severely affected by this problem, because of the relatively high tidal range that characterizes much of this state.

b. Quality of older data. According to NOS hydrographic personnel, relative errors are comparable in both older and newer bathymetric datasets. However, absolute errors in the navigation of older surveys can create mismatches when piecing together survey data to form a large grid. In some cases, TIME has resorted to horizontally "nudging" entire survey datasets to obtain better agreement with known bathymetric and topographic features.

c. Geodetic datum issues. Horizontal and vertical geodetic reference levels can vary between datasets, depending on the source. Documentation can be poor, especially in the case of older data. If not properly accounted for, substantial offsets can occur when merging datasets.

3.3.2 Source Specification.

In contrast to grid development, source specification is less a technical problem than a scientific/philosophical issue. The numerical results for any particular tsunami model run are, of course, sensitive to the initial conditions. Physically, the initial condition represents the form of the initial sea surface deformation due to the geophysical disturbing force -- an earthquake and/or landslide, for example. Two approaches will be briefly discussed here.

a. Seismic forecasting. This is currently the essential scientific/philosophical thrust of the NTHMP inundation mapping program. This requires that we understand the seismic dynamics and history of a region as well as possible, so that a "worst case" scenario can be developed that is plausible and scientifically defensible. As emphasized by several community members, our knowledge of fault zones and their dynamics is currently inadequate, and much more research is needed (see Appendix). Meanwhile, the process of developing these worst case sources remains very uncertain. As evidence of this uncertainty, we note that (a) neither "Seismic Gap" theory nor the competing "Seismic Cluster" theory yield reliable forecasts of large earthquakes, and neither claims to predict the event in any more detail than the magnitude and general region of the epicenter and (b) frequently, "new faults" are discovered after major earthquakes.

Finally, having an exact knowledge of classic fault plane parameters does not guarantee that tsunami initial conditions will be correctly specified. This is because studies of tsunamis over the last decade have generally shown that crustal deformation models spread seismic energy over too large an area and, when used as tsunami sources, consistently produce offshore tsunami heights that are too small, resulting in runup values that are significantly less than observed. To compensate for this known error, an earthquake asperity is added just offshore of the coastal zone of interest, in order to augment the height of the initial tsunami waveform.

b. Probabilistic Methods. "Probabilistic" or "response" methods represent a different approach, in which an ensemble of model runs are carried out, each with different initial conditions which vary over some multi-dimensional parameter space (such as wave height, period and direction). The suite of initial conditions must, of course, also be reasonable and consistent with the known history and geophysics of the region.

A recent study has used probabilistic methods to explore the sensitivity of numerically computed offshore tsunami wave height to variations in the spatial distribution of slip on a fault for a constant magnitude earthquake ("Complex Earthquake Rupture and Local Tsunamis," Eric Geist, unsubmitted draft manuscript). It was found that the average variation of nearshore tsunami wave height was about 3, depending on the location and peak value of high-slip patches on the fault plane. Maximum variations were as high as 6.6, and a typical patch length scale was about 20-40 km.

4. How to go forward ...

If NTHMP inundation mapping capability is to be improved, then the methodologies for dealing with the two primary problems that delay production -- grid development and source specification -- must be improved.

4.1 Grid Development. To improve and speed up the grid development process

(a) the current role of TIME must change from one of "grid-supplier" to "data- and tool-developer/supplier," and

(b) NTHMP modelers must perform the actual design and construction of the grid

The TIME Center is uniquely positioned to acquire and develop bathymetric and topographic datasets suitable for tsunami inundation modeling. As part of a NOAA research laboratory, TIME is physically co-located with the NOS Pacific Hydrographic Branch and the Pacific representative for NOAA's NGDC. PMEL also maintains a robust Information Technology infrastructure to support database and software tool development, based on web and GIS technology.

NTHMP modelers are uniquely qualified to construct a grid that is optimal for their particular application, given the best available bathymetric and topographic data and efficient tools to perform the necessary analysis, visualization, merger and editing.

The goal is to improve the production speed and quality of computational grids. and this more natural division of labor should:

(a) improve data availability and access,
(b) make the mechanics of grid construction easier and more efficient,
(c) reduce time spent in iterative exchanges between modelers and TIME staff, and
(d) bring the local knowledge of the modeler directly to bear on the final grid product.

Specific recommendations to reach this goal are as follows.

Recommendations to improve computational grid development

A. Formal arrangements and contracts with appropriate organizations should be developed to increase the availability of bathymetric and topographic data and replace the current ad-hoc procedures for data acquisition. This will require additional NTHMP funds for such things as digitizing of NOS smooth sheets by NOS or NGDC, or the special processing of some types of data, such as LIDAR. As an example, the cost to digitize a typical smooth sheet is $2K to $4K, and the construction of a grid for Sitka, Alaska would require the digitization of about 10 smooth sheets, for a total cost of $20K - $40K.

B. TIME should develop a web-based interface and NTHMP bathymetric and topographic database, to ease the process of assessing data availability for a coastal region of interest, and to provide easy access, visualization and downloading of data by NTHMP modelers.

C. TIME and the modeling community should mount a focussed effort to develop a standard methodology for grid development, to speed the mechanics of grid construction. This effort should also include the implementation of a suite of appropriate visualization, editing, and data merger software tools, and exploit web and GIS technology. An inventory should first be made of individuals currently working on this problem, and their existing software capabilities, to assess the difficulty of implementing the methodology. **If necessary**, a small workshop should be convened to design a strategy and develop an implementation plan.

D. TIME should assume responsibility for the implementation, testing and distribution of grid development software to NTHMP modelers. TIME should also be responsible for periodic upgrading of the code as a result of improvements developed by modelers, and for the continued maintenance and documentation of the code. This would promote uniformity, the systematic improvement of the grid construction capability over time, and the continuing documentation and support of the capability.

E. NTHMP modelers should assume responsibility for the actual construction of the computational grid, using software and data maintained and provided by TIME.

4.2 Source specification. Efforts to forecast the location and the key tsunami-generating characteristics, in appropriate detail, for future earthquakes, landslides and other geophysical events should continue. These studies to better understand regional geo-tectonics, slope instability, and other potential sources of tsunami events are fundamental scientific issues that are undeniably critical to the goals of the NTHMP.

To complement this geophysical forecasting effort, a more engineering-oriented approach should be developed, based on probabilistic and/or "design wave" concepts. Informed by local knowledge of the geophysical setting, this approach would involve multiple simulations of a suite of appropriate geophysical sources and/or input waveforms to develop a suitable worst-case scenario for emergency management purposes.

The general concept is not new; it is also known as the "response method," and is routinely utilized in a number of engineering and scientific disciplines. USGS and other scientists have developed probabilistic hazard assessment techniques for earthquakes and, as previously noted, USGS researcher Eric Geist has recently exploited this approach to conduct a sensitivity study of (linear) tsunami propagation. Some development will be required, however, to extend and apply this concept to the problem of (nonlinear) tsunami inundation.

Specific recommendations on this issue are as follows.

Recommendations to improve development of worst-case scenarios

A. TIME and NTHMP modelers, together with other tsunami scientists, should develop a methodology for assessment of tsunami inundation hazard using a probabilistic and/or response method approach.

B. A literature search for relevant studies should be conducted and knowledgeable scientists should be identified and contacted, to assess the feasibility and difficulty of developing this methodology. If necessary, a workshop should be convened.

C. A report on this effort should be provided to the NTHMP Steering Group at the next meeting.

Appendix A. Community input to "Lessons Learned ..."

THE FOLLOWING REQUEST FOR INPUT WAS SENT

Subject: Request for input Date: Wed, 04 Oct 2000 11:45:44 -0700
From: "Frank I. Gonzalez" <gonzalez@pmel.noaa.gov>
Organization: NOAA/PMEL To: Antonio Baptista <baptista@amb2.ccalmr.ogi.edu>, Ed Myers <emyers@ccalmr.ogi.edu>, George Priest <george.priest@state.or.us>, Dave Oppenheimer <oppen@alum.wr.usgs.gov>, Roger Hansen <roger@giseis.alaska.edu>, Chris Jonientz-Trisler <Chris.Jonientz-Trisler@fema.gov>, George Crawford <g.crawford@emd.wa.gov>, Brian Yanagi <byanagi@scd.hawaii.gov>, Gerard Fryer <gerard@hawaii.edu>, Gary Brown <Gary_Brown@ak-prepared.com>, Lori Dengler <lad1@axe.humboldt.edu>, Costas Synolakis <costas@rcf.usc.edu>, Elena Suleimani <elena@giseis.alaska.edu>, Mark Darienzo <mdarien@oem.state.or.us>, Kwok Fai Cheung <cheung@oe.eng.hawaii.edu>, "tim.walsh" <tim.walsh@WADNR.gov>, "John.BEAULIEU" <John.BEAULIEU@state.or.us>, Rich_Eisner <Rich_Eisner@oes.ca.gov>, Phyllis_Cauley <Phyllis_Cauley@oes.ca.gov>, "carl.cook" <carl.cook@fema.gov>, craig <craig@geophys.washington.edu>, scott_simmons <scott_simmons@ak-prepared.com>, "lu.clark" <lu.clark@state.or.us>, "richard.przywarty" <richard.przywarty@noaa.gov>, "Laura.Kong" <Laura.Kong@fhwa.dot.gov>, "Michael.Hornick" <Michael.Hornick@fema.gov>, kerre_martineau <kerre_martineau@ak-prepared.com>
CC: titov <titov@pmel.noaa.gov>, bernard <bernard@pmel.noaa.gov>, mofjeld <mofjeld@pmel.noaa.gov>, gonzalez@pmel.noaa.gov

Dear All:

TIME is charged with the following task:

ACTION ITEM: The Steering group requested an assessment of lessons learned and how to go forward on where and how to map areas.

ACTION: TIME to collect and summarize data.

Each of you has a unique perspective on developing inundation maps, based on your own personal experience over the last few years. So ... this is a request for your input.

What do you consider your own most valuable

"Lessons Learned"

and how should we

"go forward on where and how to map areas ?"

A 16 October or earlier response will be appreciated. This will give us about 4 weeks to put together a report for the 14 November meeting in Hilo.

The next 5-year plan should greatly benefit from this exercise

Thanks,

Frank Gonzalez and Vasily Titov
TIME Co-Directors

THE FOLLOWING REPLIES WERE RECEIVED (IN CHRONOLOGICAL ORDER)

Subject: Re: Request for input
Date: Wed, 04 Oct 2000 20:26:44 -0700
From: Rich_Eisner@oes.ca.gov
To: gonzalez@pmel.noaa.gov

I got in trouble when I raised this issue in Seattle, but here goes again....

We are now faced with the need to rapidly complete preliminary inundation projections for the ENTIRE coast of California. This is what happens with you produce pretty maps -- everyone wants one for their jurisdiction NOW! The cost of the first four stretches of coast was ~ $50,000 each. How should we go forward this year? I suggested (trouble) that we convene an expert panel to review the results of the first several years of modeling and determine the sensitivity of the modeling techniques to various input parameters. Where would a simple model suffice over a more complex 2D or 3D model? Where can we interpolate between areas where detailed models have been run to provide low density (low population) areas a reasonable inundation estimate for evacuation planning? I'm thinking here of the Humboldt, Mendocino, Sonoma, Marin and San Luis Obispo county areas were the population is small and the coastline long.

I have proposed to Costas that he convene such a expert panel this year to determine the priorities and apporaches to give California numbers for the entire coast during FFY 2000. With the funding, he would also proceed with a detailed model for Humboldt Bay to Crescent City, which was going to be done by TIME but dropped out of the program. The panel would also

recommend those areas that should be mapped (and by what approach) in the
out years (FFY 2001----)

Subject: RE: Request for input
Date: Tue, 10 Oct 2000 08:33:01 -0700
From: Crawford George <G.Crawford@EMD.WA.GOV>
To: "'gonzalez@pmel.noaa.gov'" <gonzalez@pmel.noaa.gov>, Antonio Baptista <baptista@amb2.ccalmr.ogi.edu>,
Ed Myers <emyers@ccalmr.ogi.edu>, George Priest <george.priest@state.or.us>,
Dave Oppenheimer <oppen@alum.wr.usgs.gov>, Roger Hansen <roger@giseis.alaska.edu>,
Chris Jonientz-Trisler <Chris.Jonientz-Trisler@fema.gov>, Crawford George <G.Crawford@EMD.WA.GOV>,
Brian Yanagi <byanagi@scd.hawaii.gov>, Gerard Fryer <gerard@hawaii.edu>,
Gary Brown <Gary_Brown@ak-prepared.com>, Lori Dengler <lad1@axe.humboldt.edu>,
Costas Synolakis <costas@rcf.usc.edu>, Elena Suleimani <elena@giseis.alaska.edu>,
Mark Darienzo <mdarien@oem.state.or.us>,
CC:
titov <titov@pmel.noaa.gov>, bernard <bernard@pmel.noaa.gov>, mofjeld <mofjeld@pmel.noaa.gov>,
"Jardine, Sheryl" <s.jardine@EMD.WA.GOV>, Crawford George <G.Crawford@EMD.WA.GOV>,
Uphaus Maillian <M.Uphaus@EMD.WA.GOV>

Frank,

I sure hope these emails are getting to you - we are having lots of problems with our server.

We need to keep up the support of the mapping effort on the coast - another words, go to the next generation of maps for those areas based on requirements from the communities (I believe you heard many of those needs at our public forums in November 99). We also need to make sure that maps are transferable to HAZUS for local emergency management use.

Look at working tsunami/landslide issues in the Puget Sound - areas of high population (while I support coastal work, I also feel that we need to be working areas of high population and high economic impact areas).

The contract setup for doing tsunami mapping is not conducive to good management practices - i.e., money is sent to EMD who in turns gives it to DNR who has to work with OGI for the modeling effort. However, there is no contract in place between DNR and OGI or us. We therefore, have no control over timelines etc. We need to look at this issue and develop a better way of doing business.

Regards,

George

Subject: RE: Request for input
Date: Wed, 11 Oct 2000 14:10:22 -0700
From: Crawford George <G.Crawford@EMD.WA.GOV>
To: "'gonzalez@pmel.noaa.gov'" <gonzalez@pmel.noaa.gov>
CC: Uphaus Maillian <M.Uphaus@EMD.WA.GOV>, "Jardine, Sheryl" <s.jardine@EMD.WA.GOV>, Crawford George <G.Crawford@EMD.WA.GOV>

Frank,

I think we can do several things to help with the modeling:

1. Either at the state level or at national level - solicit input by emergency managers and other public officials who would use the inundation maps to see (a) if the maps meet their needs and what they are using them for (b) solicit ideas on what improvements they would like to see and how those improve maps would be used.
2. Now that we receive our tsunami funds straight from NOAA, I would recommend that mapping funds go straight to DNR and that DNR, the modeling agency and TIME do a contract for the mapping effort that would have timelines by all parties and what service/product they would provide in the mapping process.

I hope this helps.

George

Subject: Re: Request for input
Date: Fri, 13 Oct 2000 09:56:47 -0800
From: Gary Brown <Gary_Brown@ak-prepared.com>
To: gonzalez@pmel.noaa.gov
CC: baptista@amb2.ccalmr.ogi.edu, emyers@ccalmr.ogi.edu, george.priest@state.or.us, oppen@alum.wr.usgs.gov, roger@giseis.alaska.edu, chris.jonientz-trisler@fema.gov, g.crawford@emd.wa.gov, byanagi@scd.hawaii.gov, gerard@hawaii.edu, lad1@axe.humboldt.edu, costas@rcf.usc.edu, elena@giseis.alaska.edu, mdarien@oem.state.or.us, cheung@oe.eng.hawaii.edu, tim.walsh@wadnr.gov,
References: 1

Hello Frank,
This response also serves as a "heads up" for an issue I will bring to the table at our meeting in Hilo.

For 2* years we have been trying to get inundation maps completed for three Kodiak Island communities. We have yet to see the first map. My understanding is that insufficient bathymetry data delayed the modeling process. I hope the modeling process will be completed very soon, so the state's Division of Geological and Geophysical Surveys can produce the maps before the end of the calendar year, when the twice-extended funding period expires.

Also disturbing to me is that recently I have been hearing rumors that bathymetry data may be insufficient for several of the "top 9" communities that our interagency committee, on which your office participated, prioritized at a meeting in November 1999.

This leads me to your first question regarding lessons learned. Collaboration between scientists and emergency managers is important in developing a sound mitigation program. However, scientists and emergency managers must bring the best information available to the table to determine the most prudent course of action. It seems that bathymetry data continues to be the Achilles heel for our inundation mapping program. What bathymetry data is available? Is it sufficient for modeling input? How can we get more? How long does it take? Where do we get it? How do we avoid a situation in which make decisions based on a belief that sufficient bathymetry data is available, only to discover on the eve of commitment that it is insufficient? When decisions by scientist and emergency managers are made, they are followed by promises to communities by emergency managers, which must be broken if the decisions are invalidated by inaccurate data. Let's work together to accomplish the mapping based on the best data we have even though is may be less than perfect.

I think your second question on where and how to map areas can also be answered based on available bathymetry data. Our interagency committee already prioritized nine communities to be mapped. We can meet again to update that priority if the bathymetry data issues I have raised can be resolved.

Thanks,

Gary

Subject: RE: [Fwd: data available]
Date: Fri, 20 Oct 2000 13:22:25 -0700
From: Antonio Baptista <baptista@ccalmr.ogi.edu>
To: gonzalez@pmel.noaa.gov
CC: emyers@ccalmr.ogi.edu

Thanks, Frank.

I just realized that this did not reach you: our "lessons learned" document is included.

-- Antonio

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Lessons learned in generating inundation maps for Oregon and Washington

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Overview

We have accumulated ten years of experience in applied tsunami research, leading to the generation by state agencies of inundation maps for multiple communities in Oregon and Washington. Such experience suggests that:

- The science and practice of tsunami prediction is still plagued by large uncertainties, stemming from, in arguably decreasing order: (a) uncertainties in the characterization of the seismic source, (b) insufficiencies in bathymetric and topographic data; and (c) model insufficiencies.
- While uncertainties are reflected in modern inundation maps, those maps should still provide useful guidelines for preparedness and emergency response. Indeed, these maps typically reflect a conservative interpretation of modeling results, tempered by common sense and anchored (where available) by historical geological information.
- State agencies play the key role in the generation of inundation maps. These agencies: (a) serve as the primary liaison to and among federal agencies, local communities and researchers; (b) make ultimate decisions on the interpretation of modeling results and any available geological data; and (c) provide community education, arguably the most valuable tool for tsunami preparedness.

- DOGAMI has been a pioneering state agency in what concerns modern tsunami preparedness, and their experience provides a useful reference template for the role of a state agency.
- While there has been significant incremental progress in applied tsunami research over the last decade, a fundamental overhaul of the approaches to source characterization and tsunami propagation and inundation is overdue. National and regional funding mechanisms do not provide adequate incentive for such an effort, and arguably even for retention of tsunami research expertise in academic institutions.
- Tsunami modeling: there is an urgent need for applied inter-model comparisons, for joint efforts towards community models, and for certification of models and modeling procedures leading to inundation maps.

The next sections describe narrower and more specific aspects of the "lessons learned", from a slightly more technical perspective. Publications from our group (not restricted to tsunamis) are listed in http://www.ccalmr.ogi.edu/baptista/publications.html. An on-line article is available at http://www.ccalmr.ogi.edu/STH/online/volume17/number1/mbp.

Seismic source

Defining the reference events for which tsunami inundation maps are generated is a significant challenge. Most tsunami simulations for Oregon and Washington used estimates of the deformation from potential Cascadia subduction zone (CSZ) earthquakes, sometimes aggravated by asperity scenarios recommended b y NOAA and designed to increase safety factors. In addition, estimates of the deformation for the 1964 Alaska tsunami have been used as reference for remote tsunami sources. Other regions of the country must make a choice among different sources (both near-field and far-field) to be used in the simulations.

Once the source regions have been identified, there are other complicating factors in the assumptions that need to be made. These include how the slip will be distributed along the fault plane, the nature of slip transition zones, the spatial coverage of these slip patterns, and the possibility of landslides or asperity effects.

For hazard mitigation purposes it seems that it is best to consider the uncertainty range, confirm that this range is geologically realistic, and to make assumptions that are biased towards worst-case scenarios. If geological evidence is available for past events from the selected source, this should guide in the assumptions needed for the computation of the source. Those are, in general, guiding principles that have been adopted in Oregon and Washington.

Data

Information regarding the three-dimensional structure of the subduction zone can be used with dislocation models that integrate point sources (instead of a single rectangular source dipping at a constant angle). If estimates of temperatures are available within the subduction zone, these may be used in estimating transition zones that may occur with the slip.

Aside from source-related information, much of the data that needs to be processed for the inundation models comes from bathymetry and topography. The vertical datums for merged datasets can often be inconsistent. It is therefore necessary to be careful when merging multiple sources of information into a single database. Bathymetry is often referenced to MLLW, yet corrections from MLLW-MSL are not always available and must be estimated based on tide gauges in the region of interest. The size of the files containing the data can be quite large – a consideration when thinking of the computational resources needed for a project.

Finally, it is important to represent as many of the bathymetric/topographic features in the grid that is used in the hydrodynamic model. For example, dunes and jetties along the coast may affect the local characteristics of the waves and their inundation. The grid needs to have enough refinement in such areas to adequately represent the physical processes. Technology is improving to add resolution in both bathymetric and topographic surveys, but in many cases end-user products still lack the resolution and frequency of update that is required. This is a challenge that needs to be addressed at a national level, and NOAA has shown promising leadership towards a solution.

Hydrodynamic model

There are many factors in the models that need to be closely monitored to evaluate their impact on the results. Many of the user-specified input parameters can play a significant role in the propagation and inundation of the waves. For example, the friction parameterization can play a significant role in the wave behavior, particularly in shallow waters and on land. Other factors such as the diffusion coefficient and time step may also impact the final results.

The grid refinement is a key issue in the numerical simulations. As the waves propagate into shallow water and interact with the coast, the spectrum of wavelengths will change significantly. In order to represent many of the higher frequencies developing in shallow regions, it is generally necessary to have quite a lot of grid refinement in those regions. How much refinement to add is a critical issue. Limiting factors in this issue involve the computational limits on the number of grid nodes (both in terms of disk space for output files and memory for the simulation) and the physical meaning of results under the shallow water theory assumptions. Conservation measures such as energy preservation can help guide how much refinement to add. For example, total energy will most likely generally be better preserved as one adds refinement. If the total energy variation over time begins to show fluctuations (rather than steady improvements), this may provide an indication of the limit of the shallow water theory.

In general, we have found that a large degree of refinement is needed, particularly in shallow regions and on land that will experience inundation from the waves. This refinement issue also ties in the issue of best representing the bathymetric/topographic data in critical areas. Often, more refinement is needed to represent many of the local features in communities at risk. A drawback to smaller grid spacing scales is the need for smaller time steps. Thus, the simulations will be more computationally intensive due to the increased number of grid points, the output files will be proportionately larger, and the simulations will take longer to the increased number of time steps. A balance needs to be found where these computational limitations do not hinder the generation of results that can be used by the states/communities, and yet those results need to be as physically meaningful as possible.

Another factor that can influence the simulations is the assumed stage of the tides. If MHHW is assumed, the results should represent a worst case scenario of inundation patterns for a given tsunami.

Interactions between the tsunami and the tides may be important in some instances, and thus it may be ideal to move in the direction of incorporating tidal forcings in the simulations.

Generating final products

Once the model has been run, the results need to be transferred in a manner that is most useful to state and community coordinators. In general, wave heights and inundation patterns will be the key piece of information for the coordinators. Kinetic energy can be important in considering hazards as well, and therefore velocity information should also be provided in conjunction with wave heights. The timing of the waves is also critical, and time histories of the simulated waves at selected locations and/or isolines of tsunami arrival times throughout a community can provide useful information in the design of evacuation routes. If data is available pertaining to past tsunami evidence in a given area (for example, geologic evidence), such information should be incorporated as best possible on the final maps. This provides the community with a sense of what the numerical models are computing contrasted with what past evidence indicates has previously occurred.

Subject: FW: Lessons learned: tsunami hazard mapping and modeling
Date: Fri, 20 Oct 2000 14:13:20 -0700
From: Priest George <george.priest@dogami.state.or.us>
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CC:
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Antonio Baptista has provided an exceptionally well thought out description of the major lessons that we have learned in our efforts to make meaningful tsunami hazard maps. The attached document is well worth your time to read and ponder. It succinctly covers the major problems that have plagued us and how we (state and federal agencies, academia) all fit into the solutions. Recognition of the importance of earthquake source as a principal problem in need of further research is particularly important for the Cascadia region.

I would add, as I have in recent meetings (Penrose, PANGA), the need for an overall Cascadia Science Plan that provides a framework to resolve the major Cascadia earthquake source issues. Once this framework is in place and cooperative partnerships have been formed, there will be a vast increase in the efficiency and speed with which we provide the answers that the public is asking us for. The next step is for some organization, preferably federal, to step forward and provide the necessary leadership and organization to accomplish this task. The Cascadia source issue should be a listed research program within FEMA, NSF, USGS, and NOAA with non-overlapping tasks that take advantage of the separate resources in each agency. State government and academia should be full partners in order to take advantage of their local knowledge bases.

My only other addition to Antonio's comments is the importance of giving ownership of local hazard maps to local government. Involving local government throughout the mapping process is crucial to their effective use of the final products. None of this does any good, if no one pays any attention to it. I have found it to be particularly effective to have county and city emergency managers work with me to set up informational meetings of interested stakeholders and participate with me in the field in checking the validity of the mapped tsunami inundation lines. This is last step is what I call passing the "sniff test." Does it make any sense when you are standing on the ground? Having the answer come up yes for both yourself as a scientist and the local official responsible for people's lives is a vital ingredient in mitigation.

Subject: Frank, Here's my latest input re PMEL/TIME/SIFT. Hal
Date: Mon, 30 Oct 2000 14:40:32 -0800 (PST)
From: MOFJELD@PMEL.NOAA.GOV
To: frank.i.gonzalez@sparky.pmel.noaa.gov, vasily.titov@sparky.pmel.noaa.gov

Frank,

Here is some input for the NTHMP 5-Yr plan. The focus is on plans; past experience is used to strengthen the arguments for choosing these approaches.

Hal

Keep the balance of warning, mitigation and education (not addressed)

Warning: Need to address the local earthquake. George Crawford is putting together a good approach to addressing this in terms of state/local/NWS response. In addition to this, the NTHMP should consider the later wave problem and well as calling a credible all-clear. With regard to this, there is a serious lack of tide gages in many areas. States should be encouraged to ask for an enhanced array of coastal tide/tsunami gages. Work should contain to integrate the DART system into the tsunami warning systems, using SIFT as a prototype.

Mitigation: For its mitigation component, the NTHMP (and TIME) should focus on the more efficient production of tsunami inunation maps.

DEMs -- The NTHMP needs to find a more efficient way of generating the digital elevation models needed by tsunami models. Obtaining adequate DEMs is a major roadblock to producing inundation maps. Many coastal communities on the priority list do not adequate bathymetric/topographic data. Therefore, there should be an option to contract for LIDAR and side-span surveys, in order to fill these data gaps.

NOAA/NOS has in place rapid processing and quality assurance systems that would speed the production of the DEMs. They have expressed an interest in collaborating with NTHMP on this. It is also possible for the NTHMP to request that certain communities be given priority for NOS bathymetric surveys.

Products -- It is basically up to the states to decide what products fit best into their tsunami planning and response programs and how they involve the local emergency managers.

For Washington, the trust is toward HAZUS/GIS, with paper maps as appropriate. A tsunami generated by a local or regional earthquake (or by a landslides) is one of several geological hazards occurring at the same time. Hence, HAZUS or another GIS system provides a quick way of overlaying these hazards for planning and response. This multi-hazard approach is becoming standard for assessing risk. In electronic form, the tsunami maps can be efficiently updated and disseminated to end-users at low cost. FEMA should encourage and help this effort.

Models -- NTHMP is not a development program, and many model comparisons have already been carried out. One possibility is to choose the standard to be the finite difference model based on the shallow-water equation. For example, Imamura's version is used internationally. If someone wants to use a different kind of model, they need to first show that they meet the standards that have already been established in the recent tsunami modeling workshops.

Still, NSF and other agencies should be encouraged to fund the development of improved models, especially in ports and harbors where the step bathymetry/topography of piers, docks, seawalls and dredged channels require more complete dynamical equations. These areas are population centers and concentration of lifelines for the surrounding regions. There is also issues of flow around buildings and structural design that these agencies should address..

Background water levels -- Running the models at MHHL is a good, conservative approach for the background water level. There are many issues of tsunami/tide/sea-level interaction which need to be addressed by research agencies. However, these are refinements that can be incorporated into second-generation inundation maps, after the research is done.

Sources -- Local earthquake and landslide sources need to be addressed, along the subduction zone and trans-Pacific sources. The focus should be on the maximal credible event for each category. USGS and NSF should be encouraged to fund research leading to a better understanding and characterization of the sources.
